Introduction to a EIC detector concept based on sPHENIX

sPHENIX Collaboration

PH✷ENIX

Overview

>>

Evolution of the 8 o'clock IR @ RHIC

Documented: http://www.phenix.bnl.gov/plans.html

Current PHENIX	*s*PHENIX (+fsPHENIX)	An EIC detector
▸ 14y+ operation 100+M$ investment ▸ Broad spectrum of physics (QGP, Hadron Physics, DM) ▸ 140+ published papers to date ▸ Completed last run 2016	▸ Comprehensive central upgrade base on BaBar magnet ▸ Rich jet and beauty quarkonia physics program → nature of QGP ▸ fsPHENIX : forward tracking, Hcal and muon ID → Spin, CNM	▸ Path of PHENIX upgrade leads to a capable EIC detector ▸ Large coverage of tracking, calorimetry and PID ▸ Open for new collaboration/new ideas

arXiv:1501.06197 [nucl-ex]

arXiv:1402.1209 [nucl-ex]

~2000   2016→2022   ~2025   Time

RHIC: A+A, spin-polarized p+p, spin-polarized p+A
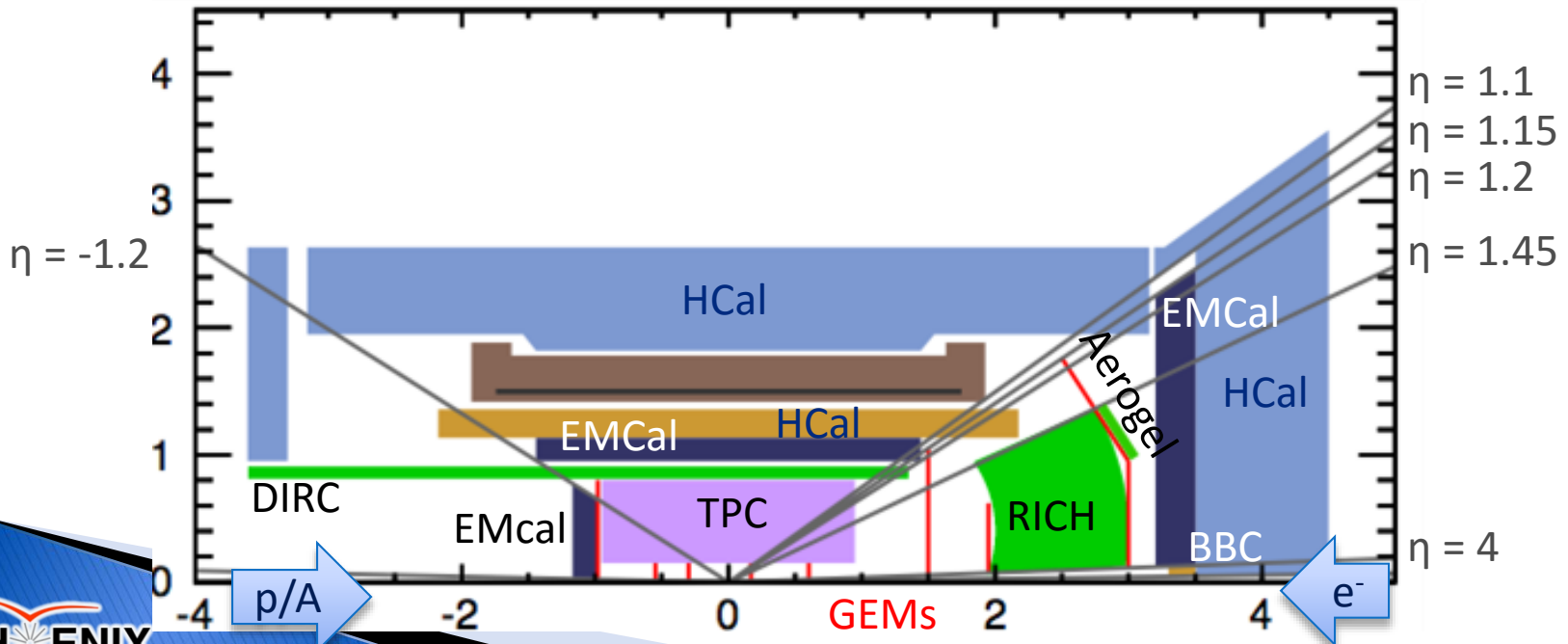
EIC: e+p, e+A

PH✦ENIX

3

Concept for an EIC Detector based on sPHENIX

- -1<η<+1 (barrel) : sPHENIX + Compact-TPC + DIRC/TOF
- -4<η<-1 (e-going) :
  High resolution calorimeter + GEM trackers
- +1<η<+4 (h-going) :
  - 1<η<4 : GEM tracker + Gas RICH/TOF
  - 1<η<2 : Aerogel RICH
  - 1<η<5 : EM Calorimeter + Hadron Calorimeter
- Along outgoing hadron beam: ZDC and roman pots

Working title: "ePHENIX"

LOI: arXiv:1402.1209

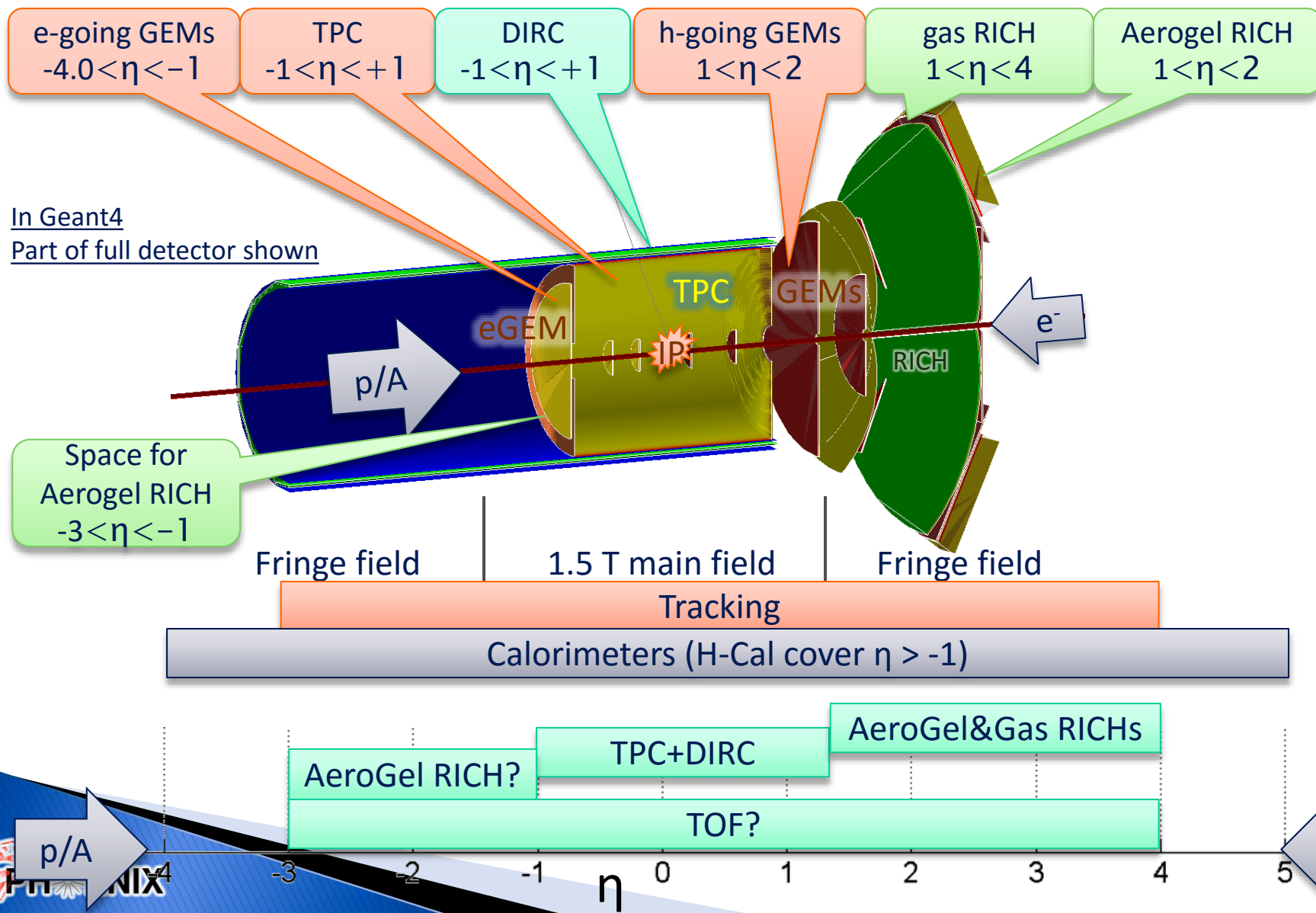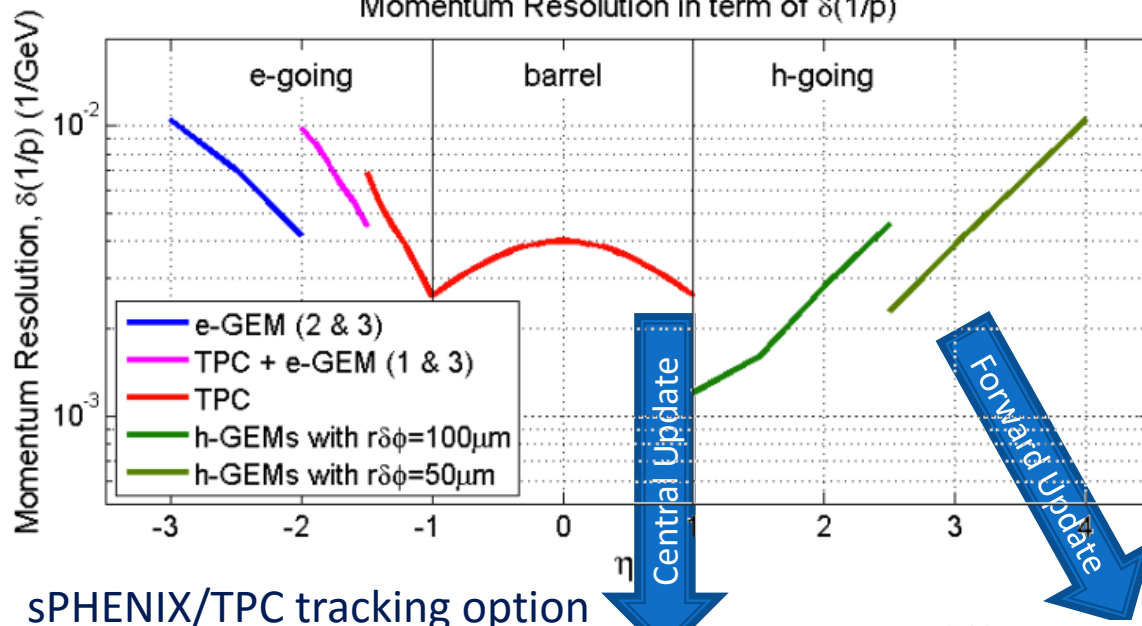Review: "good day-one detector"
 "solid foundation for future upgrades"
https://indico.bnl.gov/conferenceDisplay.py?confId=714

Tracking, PID and calorimetry coverage

e-going GEMs
$-4.0 < \eta < -1$

TPC
$-1 < \eta < +1$

DIRC
$-1 < \eta < +1$

h-going GEMs
$1 < \eta < 2$

gas RICH
$1 < \eta < 4$

Aerogel RICH
$1 < \eta < 2$

In Geant4
Part of full detector shown

TPC   GEMs

eGEM

IP

RICH

e⁻

p/A

Space for
Aerogel RICH
$-3 < \eta < -1$

Fringe field   1.5 T main field   Fringe field

Tracking

Calorimeters (H-Cal cover η > -1)

AeroGel&Gas RICHs

TPC+DIRC

AeroGel RICH?

TOF?

p/A   -4   -3   -2   -1   0   1   2   3   4   5   e⁻

η

Subsystems

Tracking

Momentum Resolution in term of $\delta(1/p)$

- e-going
- barrel
- h-going

Legend:
- e-GEM (2 & 3)
- TPC + e-GEM (1 & 3)
- TPC
- h-GEMs with $r\delta\phi$=100μm
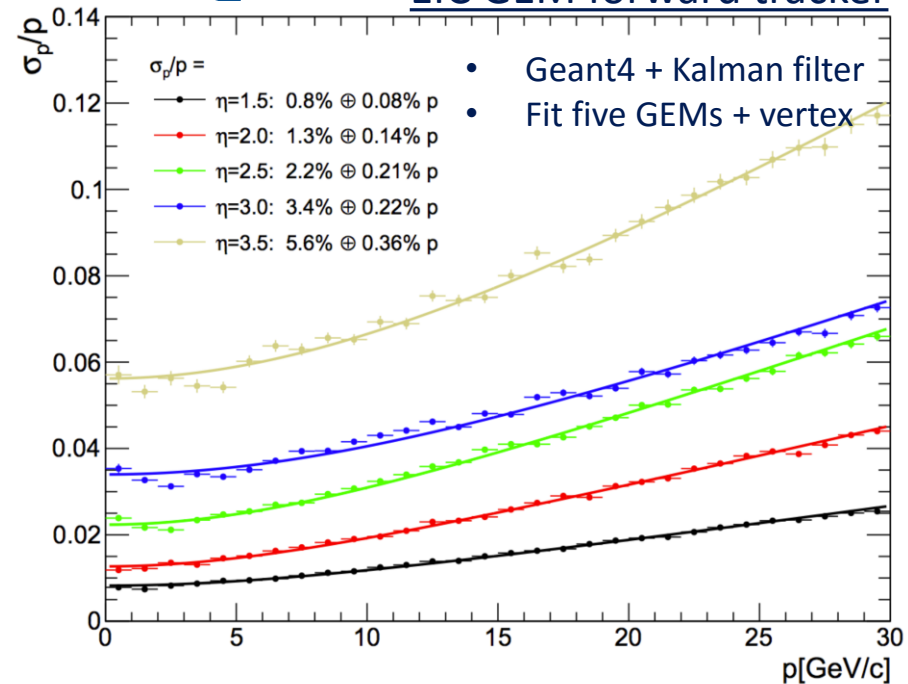- h-GEMs with $r\delta\phi$=50μm

Central Update

Forward Update

Analytical estimation
of linear resolution term
In 2012-concept
[arXiv:1402.1209v1]

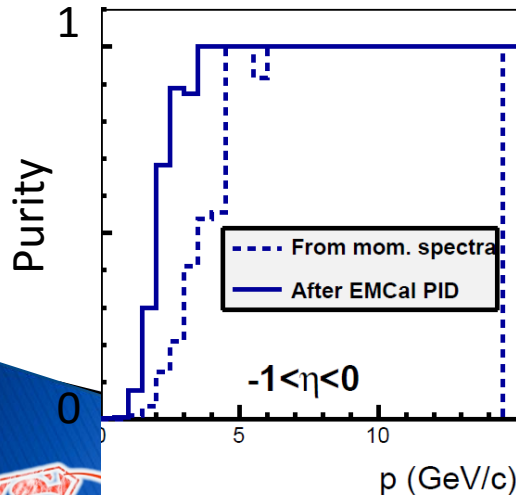MS: < 1% (low η) to 3% (η = 3)
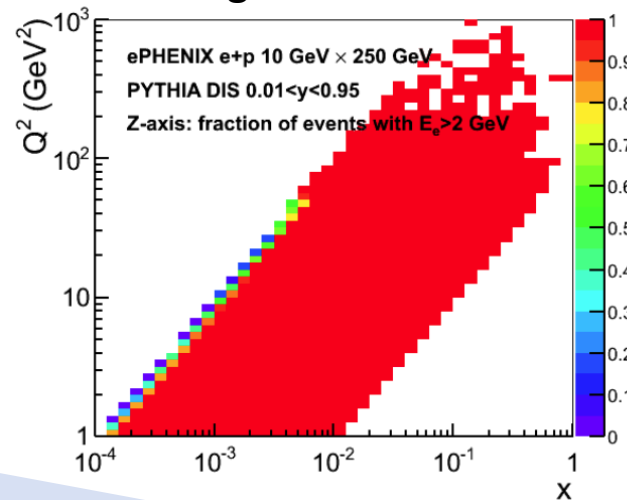
sPHENIX/TPC tracking option

- MAPS inner tracker
  + TPC (better $\sigma(r{\cdot}\phi)$ than in 2012-concept)
- Geant4 + TPC digitization + Kalman filter

χ^2 / ndf	7964 / 56
p0	$0.00742 \pm 1.296\text{e}{-}05$
p1	$0.001337 \pm 8.779\text{e}{-}07$

EIC GEM forward tracker

- Geant4 + Kalman filter
- Fit five GEMs + vertex

σ_p/p =
- η=1.5: 0.8% ⊕ 0.08% p
- η=2.0: 1.3% ⊕ 0.14% p
- η=2.5: 2.2% ⊕ 0.21% p
- η=3.0: 3.4% ⊕ 0.22% p
- η=3.5: 5.6% ⊕ 0.36% p

PH✷ENIX
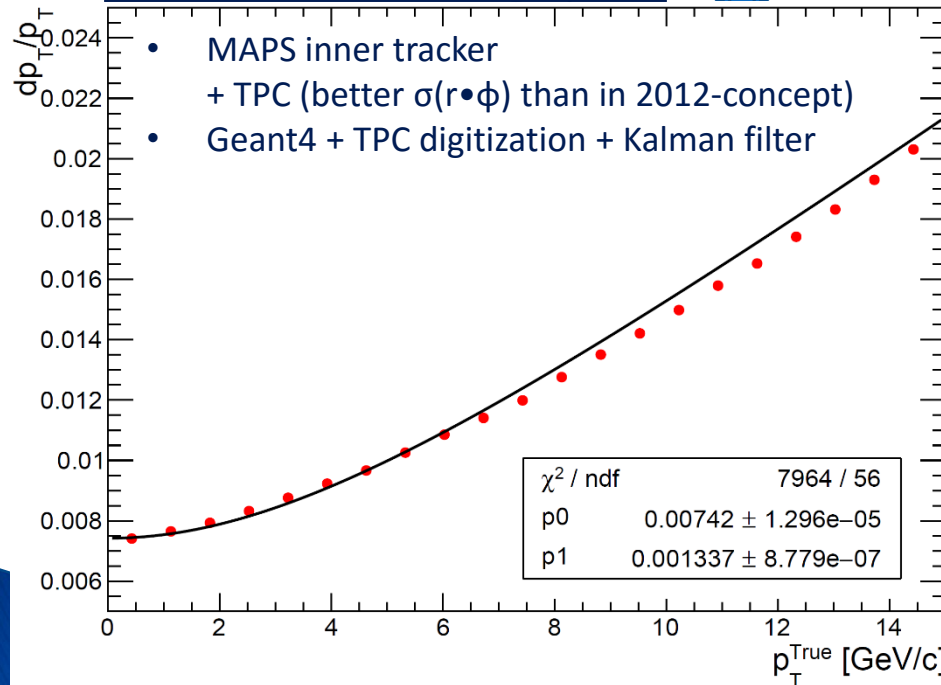
Calorimeter

- Electron identification (e-EMC, barrel EMC)
- Electron kinematics measurement (e-EMC, barrel EMC)
- DIS kinematics using hadron final states (barrel EMC/HCal, h-EMC/HCal)
- Photon ID for DVCS (All EMC)
- Diffractive ID (h-HCal)
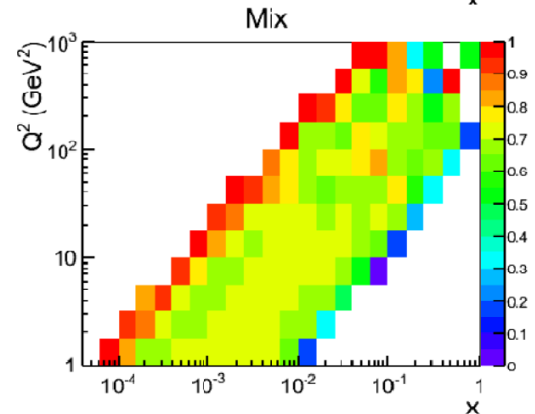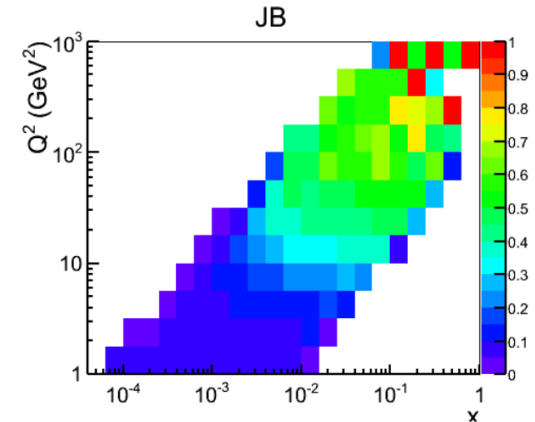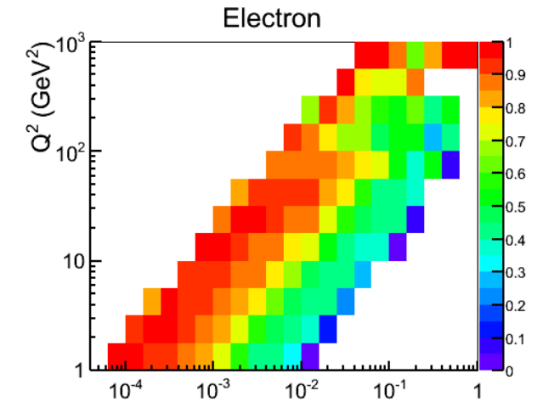- High momentum track energy measurement (h-HCal)

DIS kinematics survivability
ePHENIX 15 x 250 GeV

Electron purity after EMCal PID
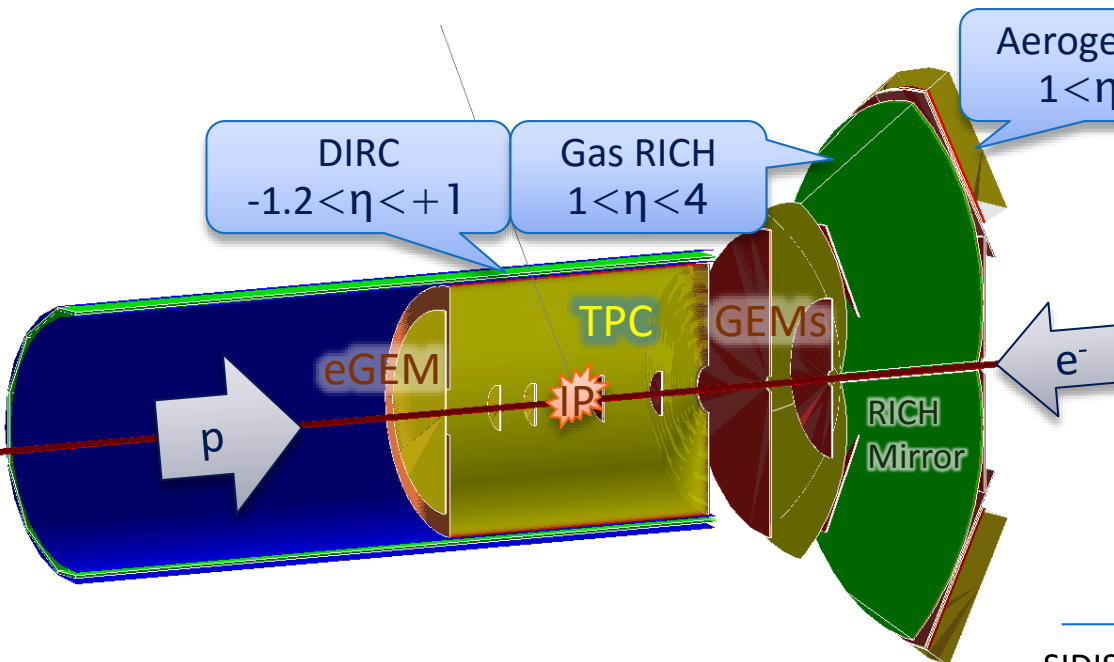

Fraction of DIS event with good electron ID

ePHENIX e+p 10 GeV × 250 GeV
PYTHIA DIS 0.01<y<0.95
Z-axis: fraction of events with E_e>2 GeV

Hadron Identification

DIRC
-1.2 < η < +1

Gas RICH
1 < η < 4

Aerogel RICH
1 < η < 2

eGEM

TPC

GEMs

IP

p

e⁻

RICH Mirror

Detector coverage for hadron PID

ePHENIX e+p 10 GeV x 250 GeV
PYTHIA DIS $Q^2 > 1$ GeV^2, $0.01 < y < 0.80$, $W^2 > 10$ GeV^2
Hadron z > 0.2

e-going   barrel   h-going

Hadron PID Coverage

Hadron Momentum [GeV] vs Pseudorapidity η

- DIRC
  - Based on BaBar DIRC design plus compact readout
  - Collaborate with TPC dE/dx for hadron ID in central barrel
- Aerogel RICH
  - Approximate focusing design as proposed by Belle-II
  - Collaborate with gas RICH to cover $1 < \eta < 2$
- Gas RICH: next slides
- Actively exploring ToF alternatives
- Considering hadron ID in en-going direction

SIDIS x-Q^2 coverage with hadron PID in two z-bins

ePHENIX e+p 10 GeV × 250 GeV
$\frac{dN_{Kaon}}{dxdQ^2}$ from PYTHIA DIS
$0.3 < z < 0.35$, $W^2 > 10$ GeV^2

y=0.95   y=0.01

ePHENIX e+p 10 GeV × 250 GeV
$\frac{dN_{Kaon}}{dxdQ^2}$ from PYTHIA DIS
$0.7 < z < 0.75$, $W^2 > 10$ GeV^2

y=0.95   y=0.01

Performance

›

PH✳ENIX

Physics performance: longitudinal structure of proton

- An EIC with this day-1 detector will significantly expand the x-Q^2 reach for longitudinal spin measurements
- EM calorimeter and tracking deliver good DIS kinematic determination and e-ID
- Precise evaluation of gluon and sea quark spin

ePHENIX electron kinematics survivability

ePHENIX gluon helicity projection
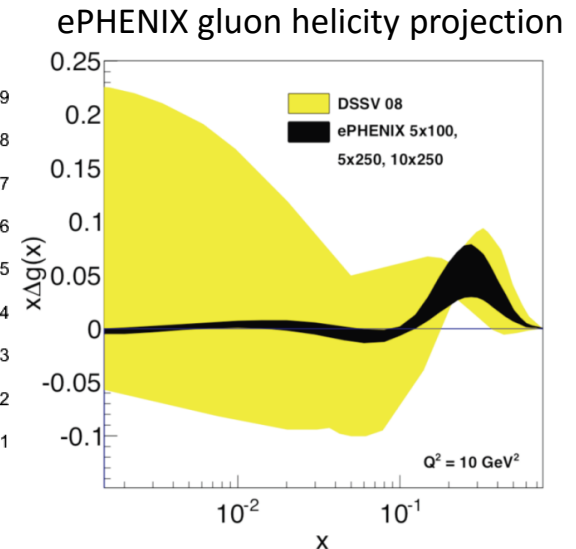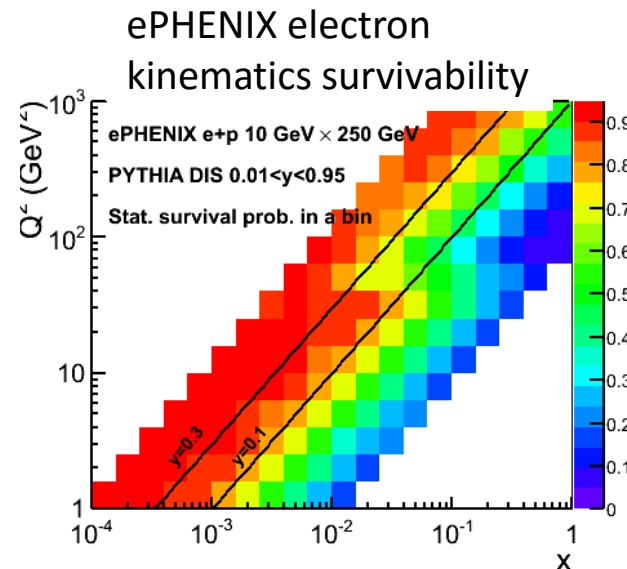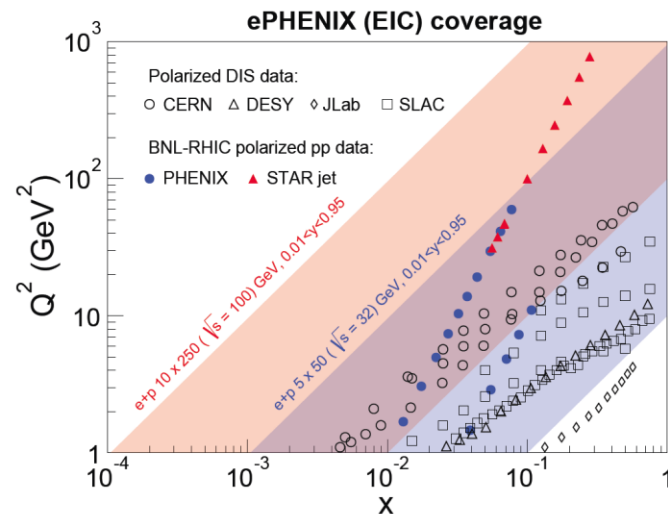
High x and Q2 region will be better determined using info from hadron final states

Physics performance: Transverse structure of nucleon

- Deliver clean measurement for SIDIS and DVCS
- Significantly expand x-Q^2 reach and precision for such measurements
- Extract sea quark and gluon's transverse motion and their tomographic imaging inside polarized nucleons
- Sensitive to the orbital motion of quark inside proton


SIDIS Sivers Asymmetries
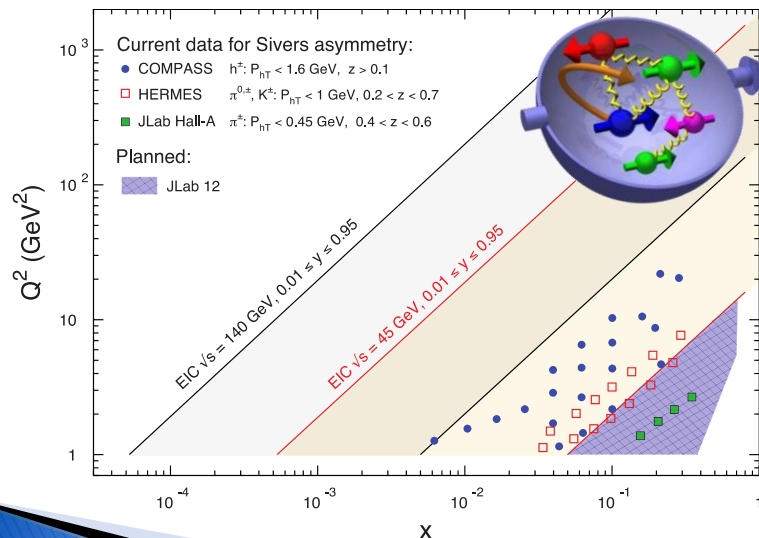
DVCS
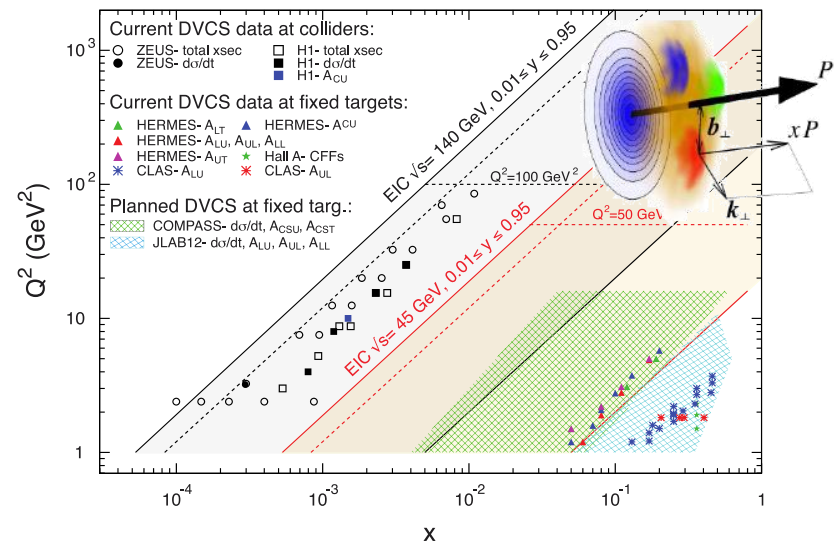
Physics performance:
nucleus as a laboratory for QCD

▸ Probe the kinematic range to inspect the transition to gluon saturation region and their nuclear size dependent

  ◦ Large H-cal coverage (-1<η<+5) provide clean ID of diffractive events with reasonable efficiency through the rapidity gap method

▸ SIDIS in e-A collisions probe color neutralization and harmonization as it propagate through nuclear matters

  ◦ Provide a set of flexible handles : struck quark's energy and flavor, virtuality of DIS, geometry of the collision, specie of nuclei.

Probing saturation region in electron kinematics
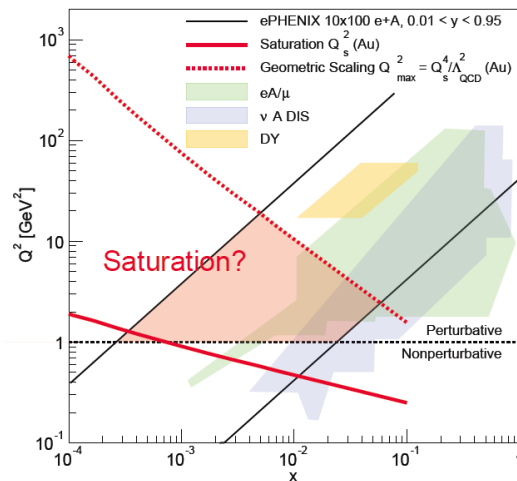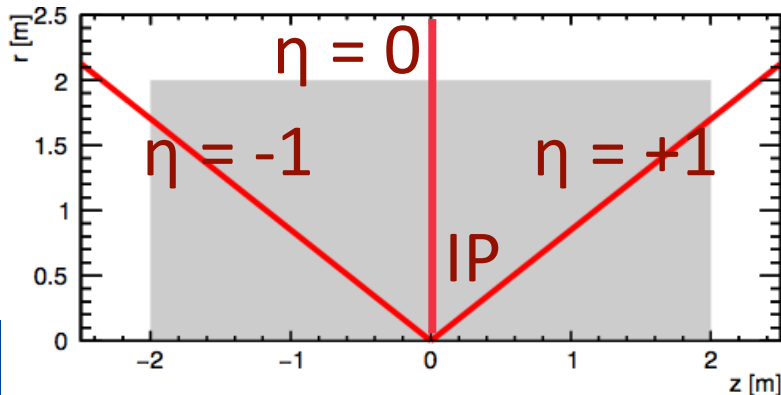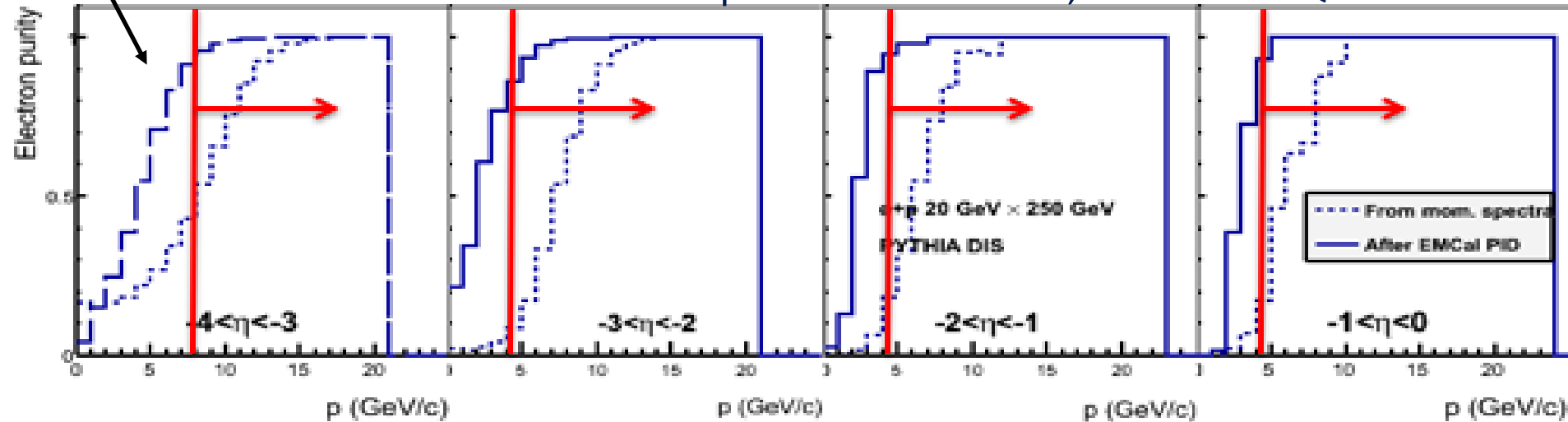

Energy transfer ν VS Q2 coverage
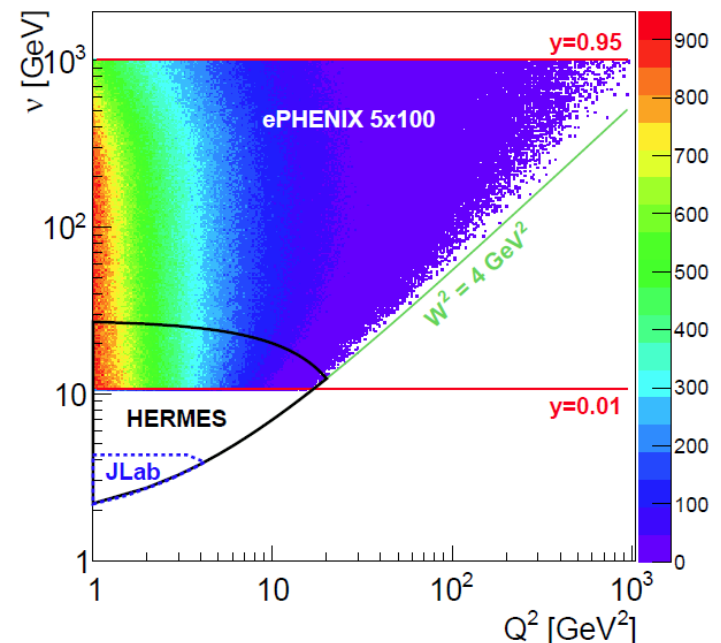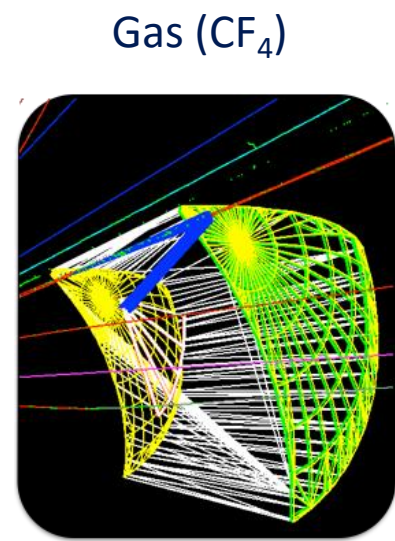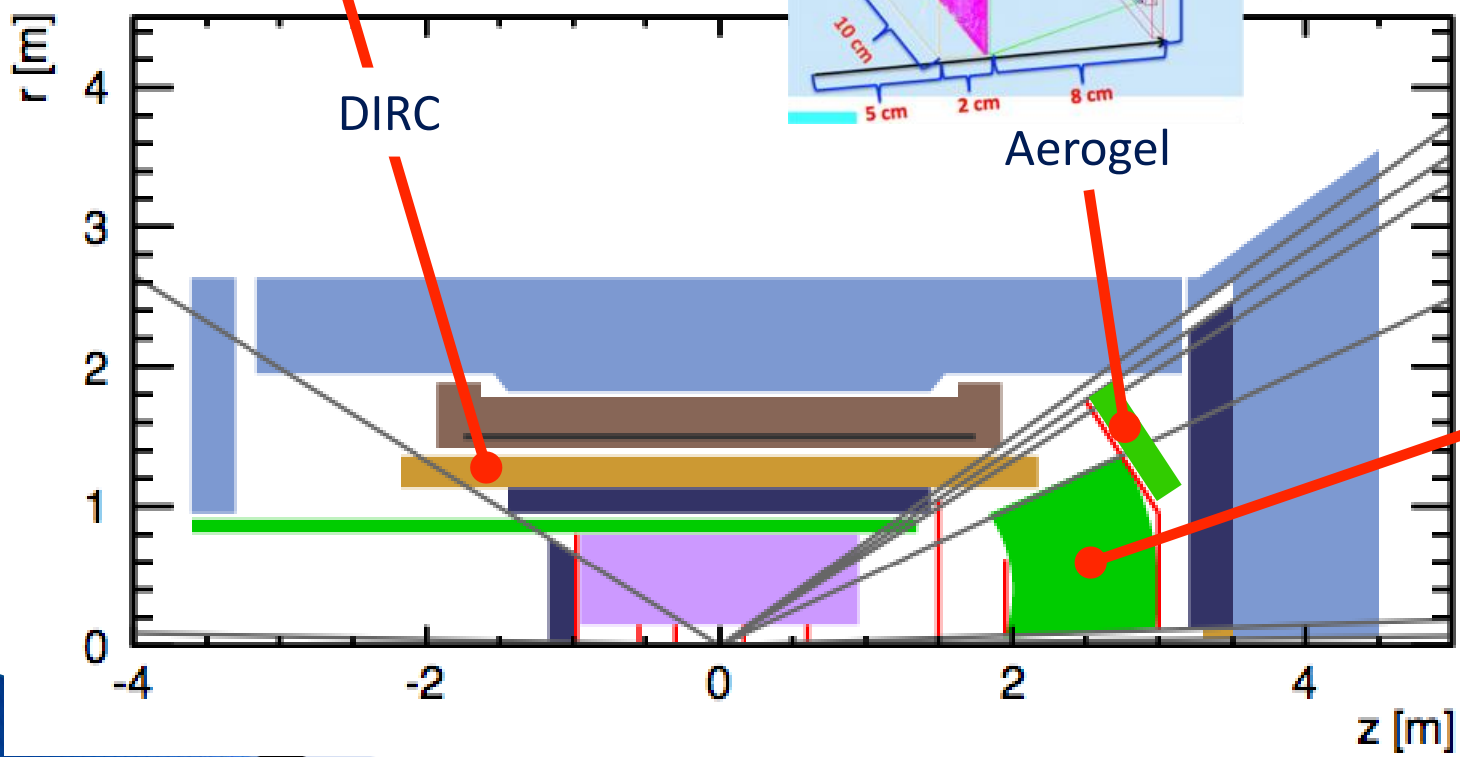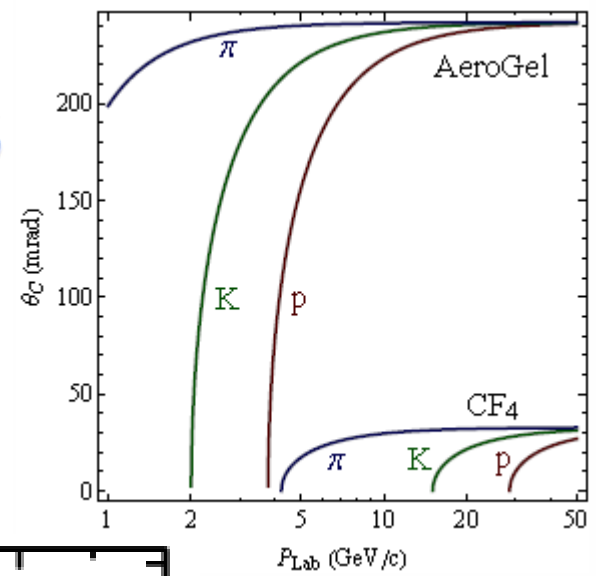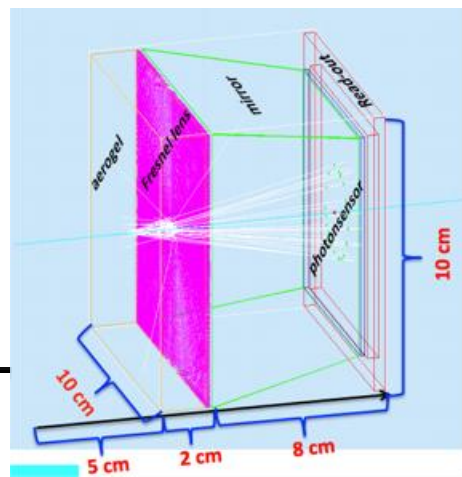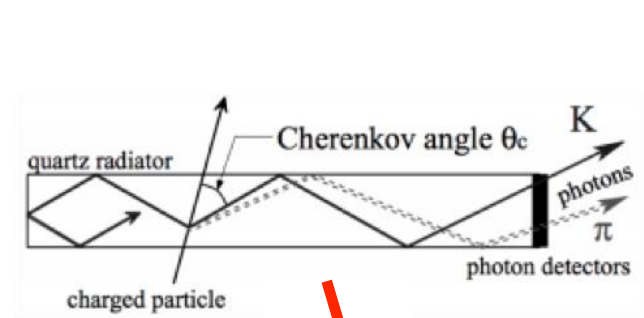
Extra information

>>

Electron Identification

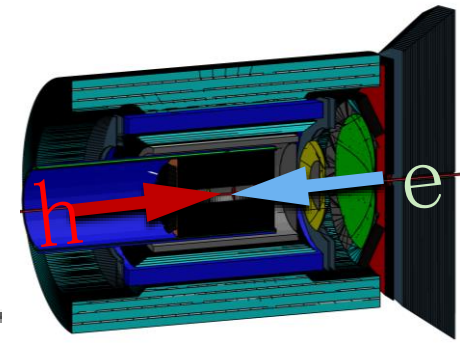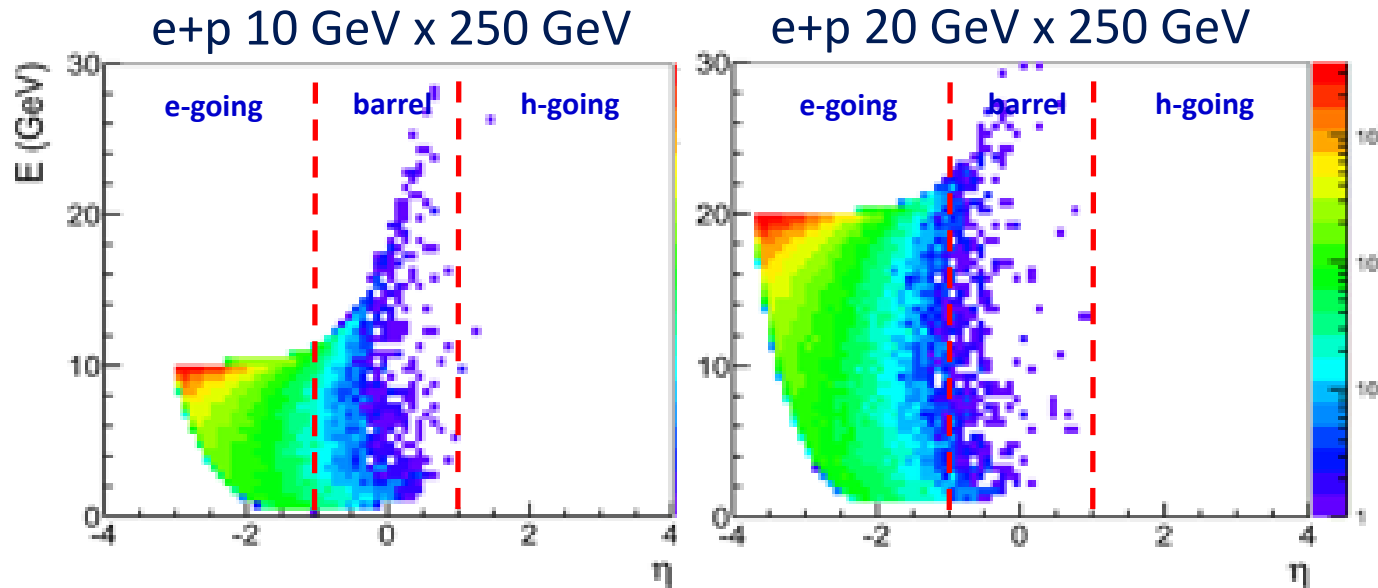No tracking or E/p

e+p 20 GeV x 250 GeV, PYTHIA DIS $Q^2 > 1$ GeV

▸ Cut on electron energy only marginally reduces x-Q^2 coverage

Particle ID: RICH Detectors

quartz radiator

Cherenkov angle θc

K

photons

π

charged particle

photon detectors

aerogel

Fresnel lens

mirror

readout

photonsensor

10 cm

10 cm

5 cm 2 cm 8 cm

θ_C (mrad)

π

AeroGel

K p

CF$_4$

π K p

P_{Lab} (GeV/c)

r [m]

DIRC

Aerogel

Gas (CF$_4$)

z [m]

PH✴ENIX

DIS: electron measurement

e+p 10 GeV x 250 GeV — e+p 20 GeV x 250 GeV

PYTHIA DIS with $Q^2 > 1$ GeV

Requirements (EIC task force):
- High purity electron ID (99%)
- Energy measurement
- Angle measurement
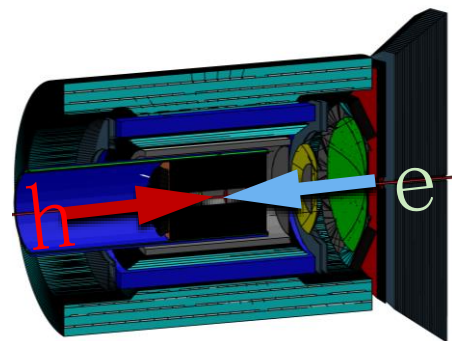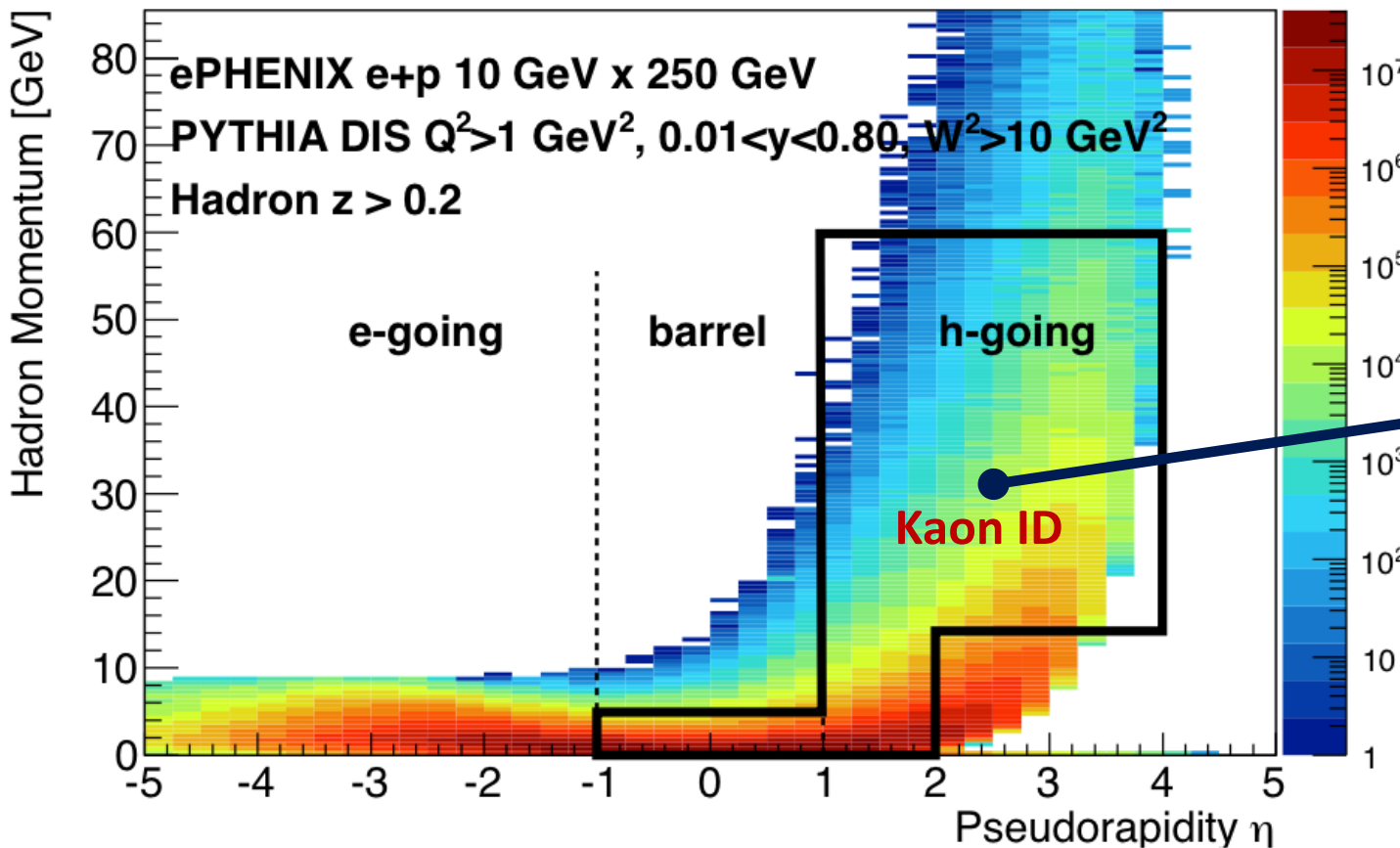- High survival probability (80%) in each x,Q^2 bin
- e-going and barrel coverage

Solution (electron-going):
✓ High resolution GEM Tracking
✓ High resolution Crystal EMCal

Solution (barrel):
✓ (sPHENIX?) Compact-TPC+(MAPS?)
✓ sPHENIX EMCal

SIDIS: Hadrons from DIS

ePHENIX e+p 10 GeV x 250 GeV

PYTHIA DIS $Q^2>1$ GeV^2, $0.01<y<0.80$, $W^2>10$ GeV^2

Hadron z > 0.2

e-going   barrel   h-going

Kaon ID

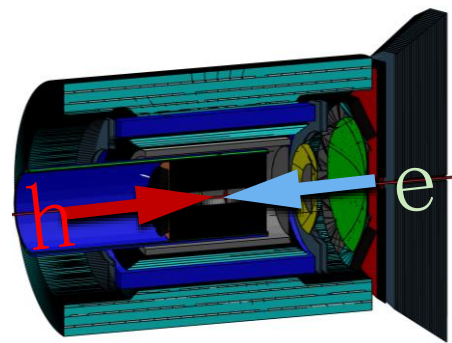**Black outline**: Identified Kaons in planned PID detectors
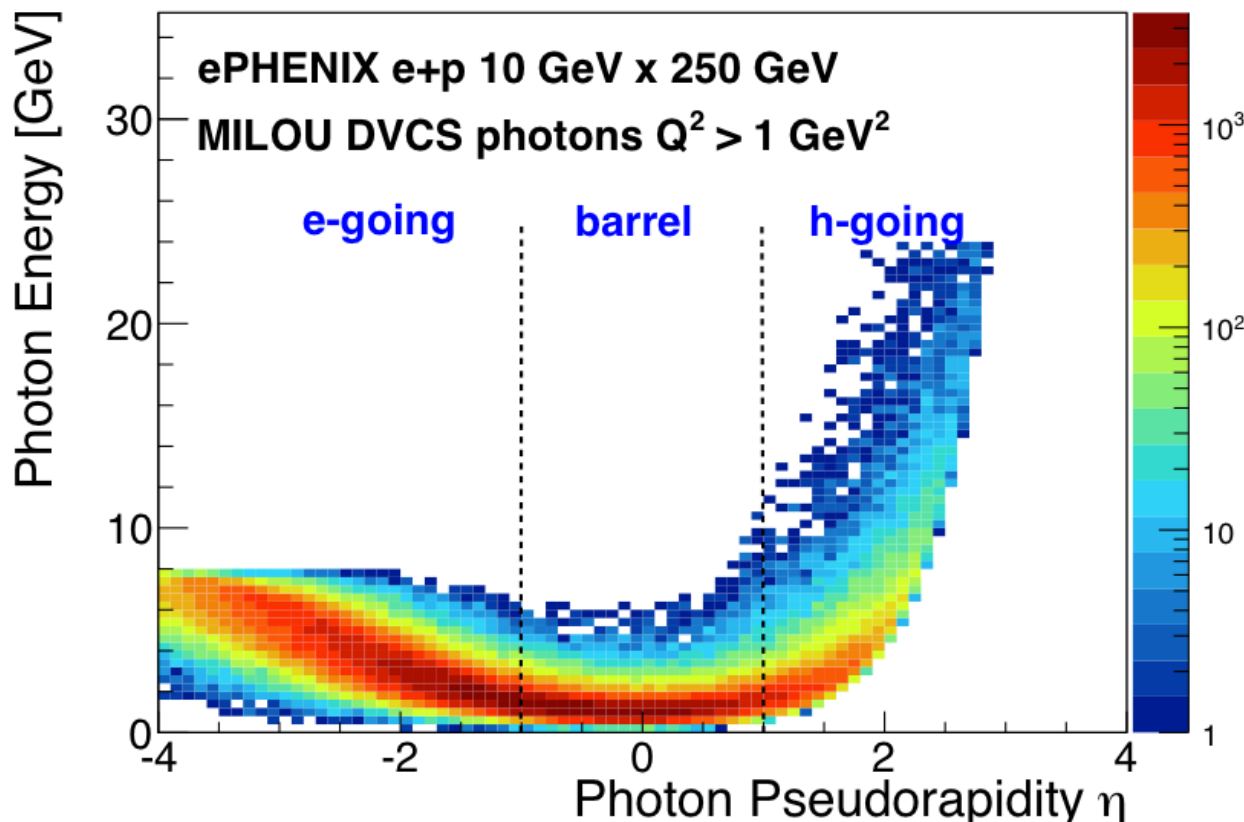
Requirements:
- Hadron ID
- 90% eff, 90% purity

Solution: RICH
- ✓ Barrel: DIRC (+TPC dE/dX for low p)
- ✓ h-going: Gas RICH (high p)& Aerogel (low p)

Exclusive DIS: DVCS photons

ePHENIX e+p 10 GeV x 250 GeV

MILOU DVCS photons $Q^2 > 1$ GeV^2

e-going   barrel   h-going

Photon Energy [GeV] vs Photon Pseudorapidity η

Requirements:

⊙ e/γ separation over large x,Q^2,t range

⊙ Confirm exclusiveness

Solution:

✓ Granular EMCal and tracking from -4<η<4

✓ Roman Pots

PH✷ENIX

19

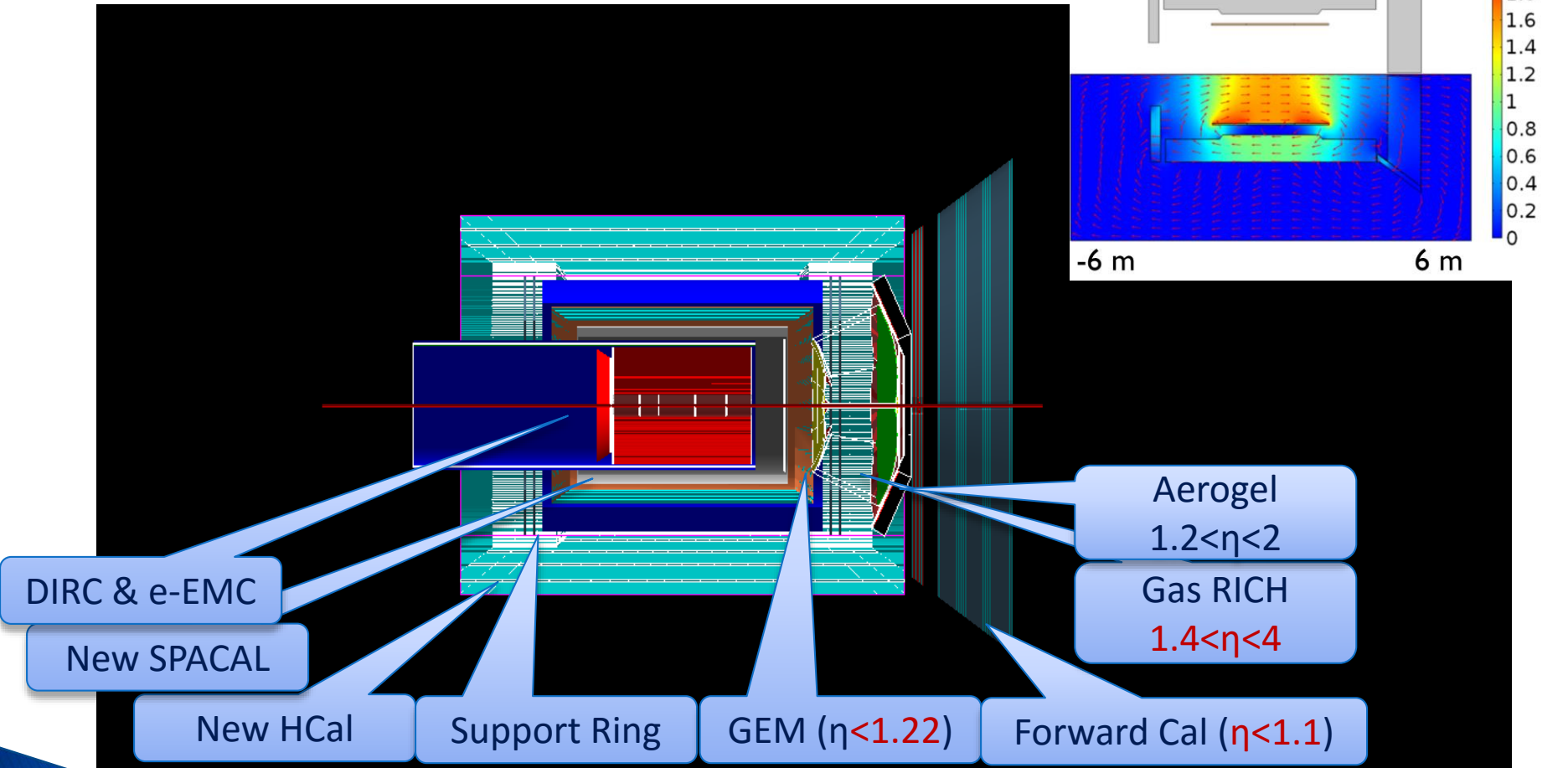# Active development from both sPHENIX and for EIC applications

▸ Software open in access:
  ◦ sPHENIX software core: https://github.com/EIC-Detector/coresoftware
  ◦ Macros to drive the software: https://github.com/EIC-Detector/coresoftware-eic
  ◦ Virtual machine under test, available to run on your computer soon

▸ Software meeting series (in open access):
  ◦ Application to sPHENIX: https://indico.bnl.gov/categoryDisplay.py?categId=93
  ◦ Application to EIC: https://indico.bnl.gov/categoryDisplay.py?categId=88
  ◦ Tutorial workshop: https://indico.bnl.gov/conferenceDisplay.py?confId=1237

▸ A few updates shown in the next section

GitHub

Detector implemented in details under Fun4All

Available under GitHub/EIC-Detector:
coresoftware-eic/macros/Fun4All_G4_ePHENIX.C

Field map/balance in COMSOL
(N. Feege, SBU)

B [T]

-6 m   6 m

DIRC & e-EMC

New SPACAL

New HCal

Support Ring

GEM (η<1.22)
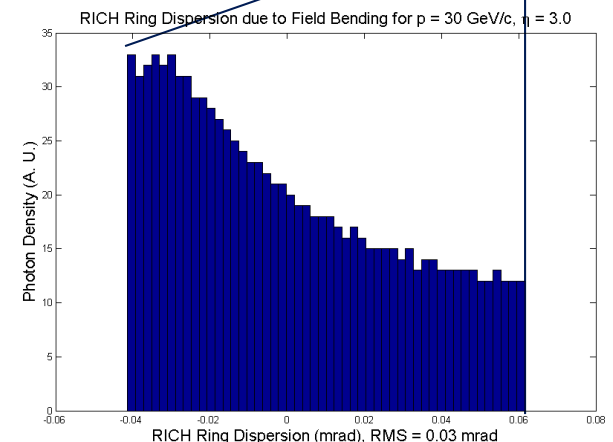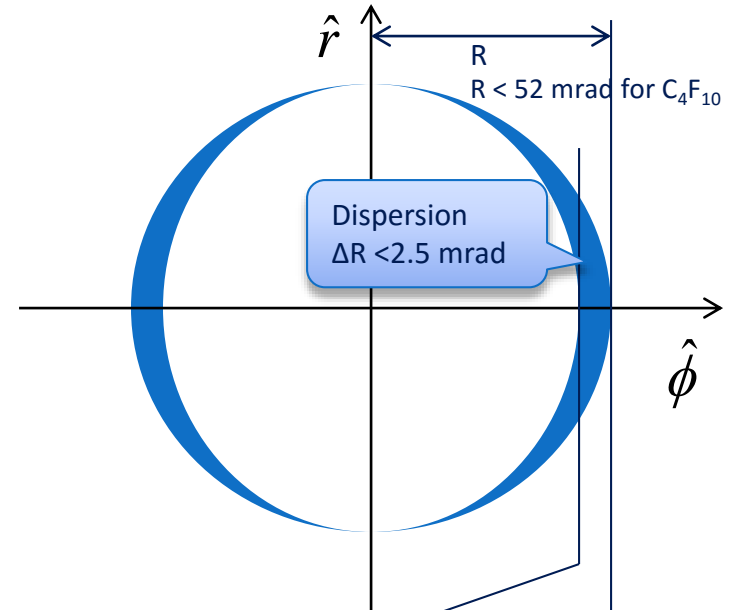
Forward Cal (η<1.1)

Aerogel
1.2<η<2

Gas RICH
1.4<η<4

Field effect - distortion for RICH

- Field calculated numerically with field return
- Field lines mostly parallel to tracks in the RICH volume with the yoke
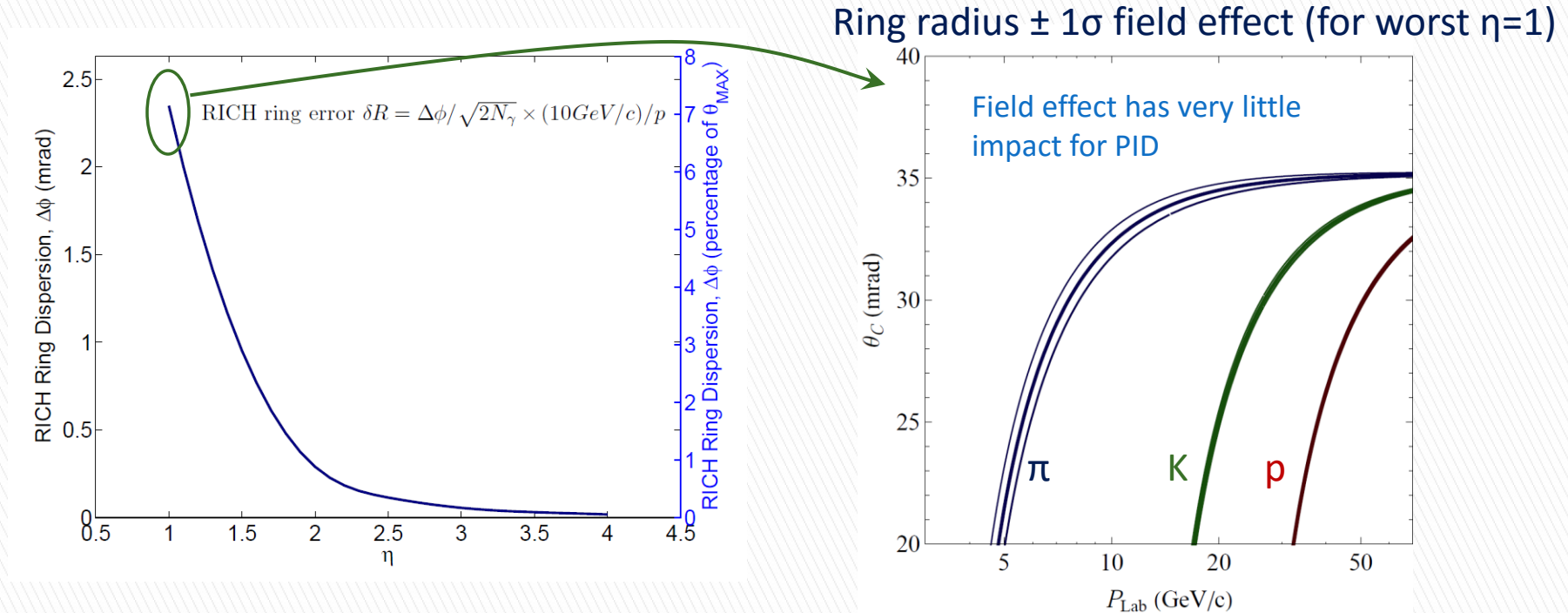- We can estimate the effect through field simulations
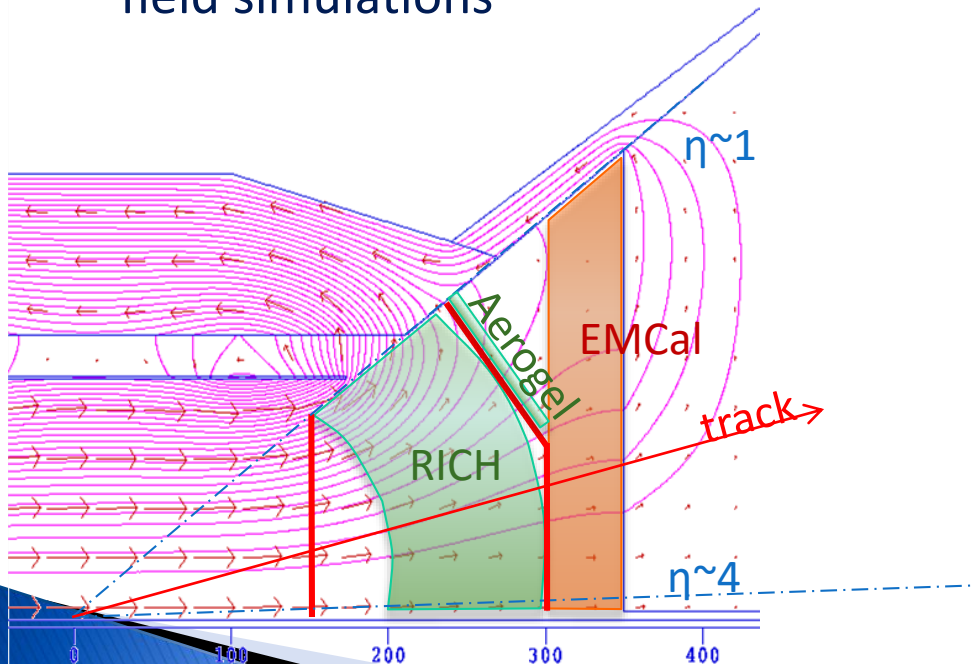
A RICH Ring:

Photon distribution due to tracking bending only

$\hat{r}$

R

R < 52 mrad for C_4F_{10}

Dispersion
ΔR <2.5 mrad

$\hat{\phi}$

η~1

Aerogel

EMCal

track

RICH

η~4

RICH Ring Dispersion due to Field Bending for p = 30 GeV/c, η = 3.0

Photon Density (A. U.)

RICH Ring Dispersion (mrad), RMS = 0.03 mrad

Field effect –
Radius uncertianty of RICH Ring

Ring radius ± 1σ field effect (for worst η=1)

RICH ring error $\delta R = \Delta\phi / \sqrt{2N_\gamma} \times (10GeV/c)/p$

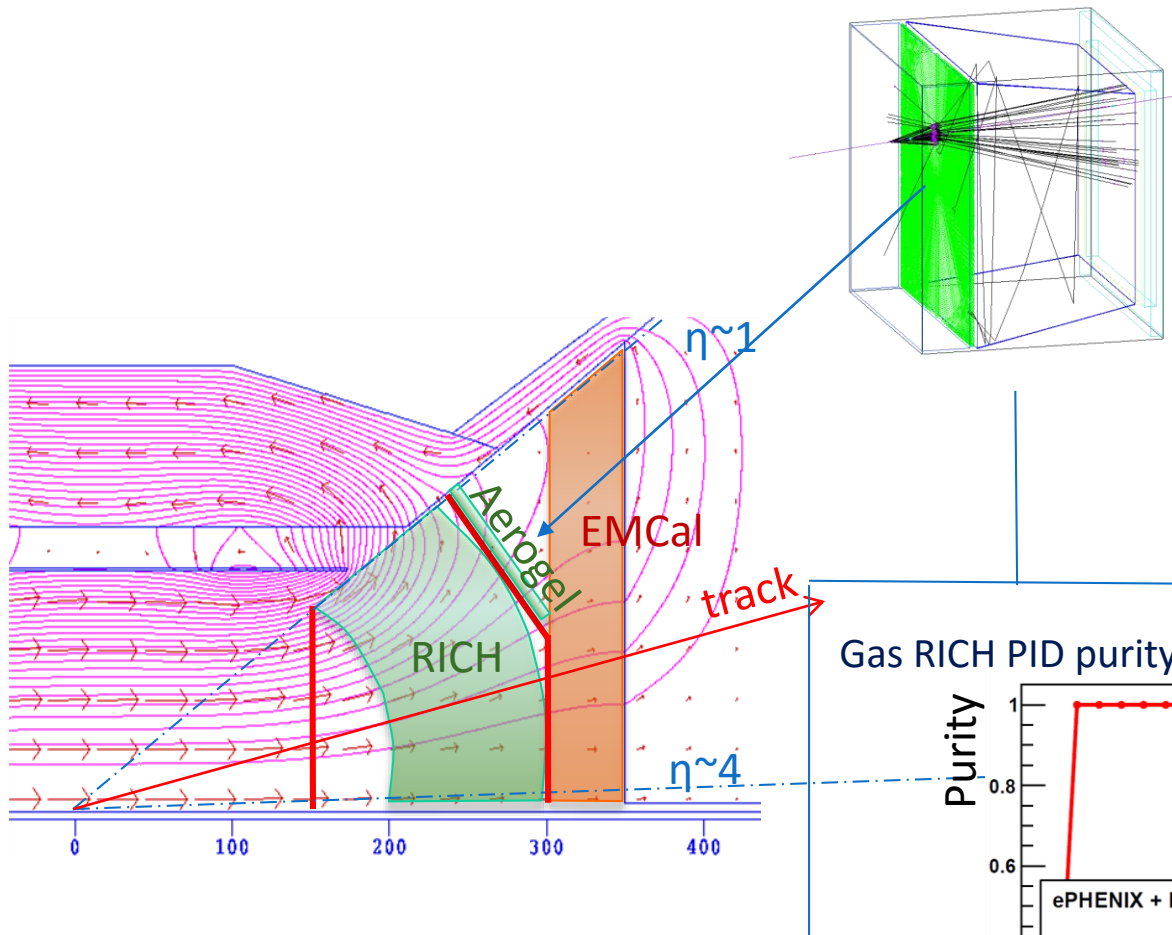Field effect has very little impact for PID
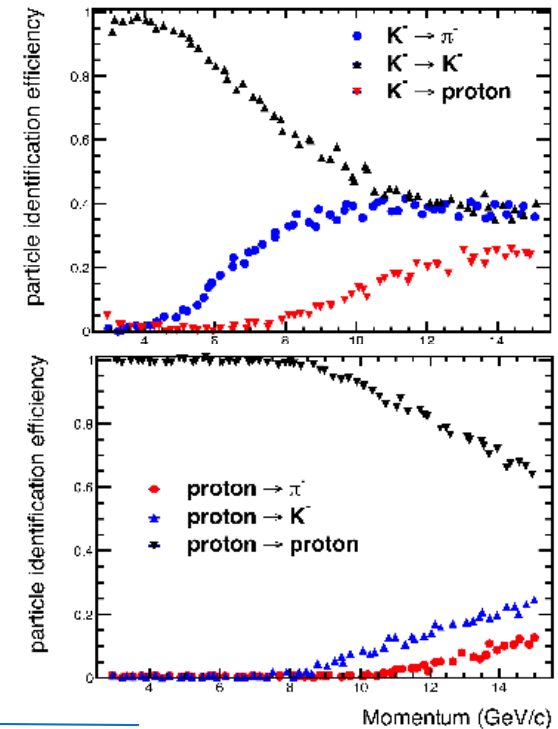
π   K   p

| Quantify ring radius error | In the respect of PID: minor effect |

23

H-going side - performance

AeroGel RICH PID eff.

Gas RICH PID purity at η=4 (most challenging region w/ δp)

EMCal

track

Aerogel

RICH

η~1

η~4

ePHENIX + PYTHIA e+p 10x250 GeV, η = 4.0

π at 90% Effic.

K at 90% Effic.

K at 65% Effic. (asym cuts)

p at 90% Effic.

Reconstructed Momentum [GeV]   <True Momentum>
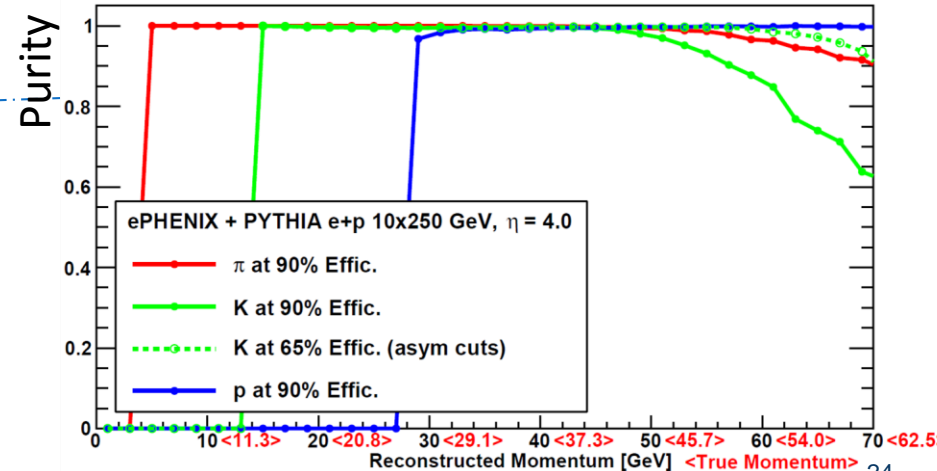
Central Barrel PID, DC + DIRC in BaBar